

ECHO PROCESSING DEVICES FOR SINGLE-CHANNEL OR
MULTICHANNEL COMMUNICATIONS SYSTEMS

DESCRIPTION

The field of the present invention is that of
5 communications. The invention relates more particularly
to variable-gain and/or adaptive filtering acoustic echo
processing devices for attenuating echo components of a
direct signal in a return signal. The invention applies
to single-channel and multichannel communications
10 systems.

Acoustic echoes occur primarily in certain types of
communication in which a remote user terminal comprises
one or more directional microphones and one or more
loudspeakers instead of an earpiece. Examples include
15 audioconference equipment and hands-free telephones, such
as mobile telephones. The source of the echoes is
simple: failing special precautions, sound emitted by the
loudspeaker(s) is reflected many times (from walls, the
ceiling, etc.), constituting as many different echoes
20 which are picked up by the microphone(s) on the same
terms as wanted speech. Thus the combination of the
loudspeaker(s), the microphone(s), and their physical
environment constitutes an echo generator system.

The acoustic echo problem has been the subject of
25 much research, both in the case of single-channel systems
(one microphone and one loudspeaker) and in the case of
multichannel systems (a plurality of microphones and a
plurality of loudspeakers). The echo problem in the
multichannel situation is similar to that in the single-
30 channel situation except that all possible acoustic
couplings between the various microphones and
loudspeakers must be considered.

The echo processing techniques most widely used
include echo suppression techniques using gain variation
35 and echo cancellation techniques using adaptive

filtering.

In a variable-gain echo suppression system, a receive gain is applied to the signal for application to the loudspeaker (the direct signal at the input of the echo generator system) and a send gain is applied to the signal coming from the microphone (at the output of the echo generator system), forming the return signal. An echo suppression system of this type is described in French Patent No. 2 748 184.

10 Receive voice activity detectors (RVAD), send voice activity detectors (SVAD), and double speech detectors (DSD) typically supply the necessary information to the modules that calculate the send and receive gains. Thus when the remote party is speaking (detected by the RVAD),
15 the send gain is reduced to attenuate the echo. If the local party begins to speak (detected by the SVAD), this constraint on the send gain is removed and the receive gain is reduced. In the event of double speech (both parties speaking simultaneously, detected by the DSD),
20 either a comparator determines which speaker is louder and gives priority to that speaker's sending direction or an intermediate setting of the send and receive gains is established.

 In an acoustic echo canceller (AEC) using adaptive
25 filtering, an identification filter estimates the acoustic coupling between the loudspeaker and the microphone and generates a signal that is used to cancel the echo. The identification filter is conventionally a programmable finite impulse response filter whose
30 coefficients need to be adapted by a predetermined algorithm for updating coefficients using an adaptation step. The coefficients are adapted on the basis of the signal to be applied to the loudspeaker. An echo canceller of this type is described in French Patent
35 No. 2 738 695.

A variable gain echo suppression system is often combined with an echo canceller to eliminate the residual echo that remains after echo cancellation.

However, the above-mentioned echo processing systems
5 have the drawback that they are not able to take account of variations in the acoustic coupling between the loudspeaker and the microphone if those variations are independent of the signal applied to the loudspeaker.

This is the case, for example, if there is an
10 external facility for adjusting the sound level reproduced by the loudspeaker (for example by means of a potentiometer). Any variation in the reproduced sound level modifies the acoustic coupling between the loudspeaker and the microphone and therefore the echo(es)
15 picked up by the microphone. The echo processing system takes account only of the signal that is applied to the loudspeaker, and not of the sound that is actually reproduced by the loudspeaker, and is therefore unable to take this kind of modification of the acoustic coupling
20 into account in its calculation process.

For example, if the sound reproduction level is reduced after the system has been initialized with a maximum sound level setting, in a double speech situation the remote speech emitted by the loudspeaker may be
25 broken up or truncated.

Similarly, if the microphone and the loudspeaker in the communications terminal being used are physically independent of each other, the distance between them may be varied, which varies the acoustic coupling between the
30 loudspeaker and the microphone, with the same consequences.

The problem is the same in a multichannel situation except that it generalized to the multiple couplings between the various microphones and loudspeakers.

35 One particular object of the present invention is to

remedy the drawbacks of prior art echo processing systems described hereinabove.

To this end, in a first aspect, the present invention provides an echo processing device for
5 attenuating echo components of a direct signal X_{1n} in a return signal Y_{2n} , said device comprising:

- means for calculating a receive gain Gr_n and a send gain Ge_n ;

- first gain application means for applying the
10 receive gain Gr_n to the direct signal and producing an input signal X_{2n} emitted into an echo generator system; and

- second gain application means for applying the send gain Ge_n to an output signal Y_{1n} from the echo
15 generator system and producing the return signal Y_{2n} .

According to the invention, this echo processing device is noteworthy in that it further comprises means for calculating a coupling variable COR characteristic of the acoustic coupling between the direct signal X_{1n} or
20 the input signal X_{2n} and the output signal Y_{1n} and in that said gain calculation means are adapted to calculate the receive gain Gr_n and the send gain Ge_n on the basis of said coupling variable.

Taking account in the device of the real acoustic
25 coupling between the loudspeaker and the microphone when controlling the variation of the receive and/or send gain applied automatically adapts the sound quality of the sent signal and the received signal as a function of changes in the acoustic environment of the echo
30 processing device and the relative position of the transducers (loudspeaker(s), microphone(s)) and as a function of the sound reproduction level chosen by the user, for example.

According to one particular feature of the
35 invention, the echo processing device comprises means for

estimating the instantaneous power of the direct signal X_{1n} or the input signal X_{2n} and the instantaneous power of the output signal Y_{1n} . The gain calculation means are adapted to calculate the receive gain Gr_n and the send gain Ge_n on the basis of a variable G determined as a function of the estimated power of the direct signal or the input signal and the estimated power of the output signal and as a function of the coupling variable COR , in accordance with the following equation:

$$G = \frac{P_{2n}}{P_{2n} + COR \cdot P_{1n}}$$

where P_{1n} and P_{2n} are respectively an estimate of the power of the direct signal X_{1n} or the input signal X_{2n} and an estimate of the power of the output signal Y_{1n} at the time concerned.

The term " $COR \cdot P_{1n}$ " in the expression for the variable G represents the energy of the sound actually picked up by the microphone, and therefore taking into account all external adjustments that are not "seen" by the system (for example the sound reproduction level).

The variable G therefore varies automatically as a function of real changes in loudspeaker/microphone acoustic coupling and the send and receive gains are therefore adapted automatically.

In a second aspect, the invention provides an echo canceller for attenuating, in an output signal Y_{1n} , echo components of an input signal X_{2n} emitted into an echo generator system, said device comprising:

- a finite impulse response identification filter whose response is representative of the response of the echo generator system, receiving the input signal X_{2n} at its input and generating a filtering signal S_n ;

- subtraction means receiving at an input a signal Y_{3n} from the echo generator system, at least one component of which is a response of the echo generator

system to the input signal X_{2n} , and the filtering signal S_n , and adapted to subtract the filtering signal S_n from the signal Y_{3n} and to produce the output signal Y_{1n} ;

- means for adapting the coefficients of the
5 identification filter as a function of an adaptation step μ_n ; and

- means for calculating the adaptation step μ_n .

This echo canceller is noteworthy in that the adaptation step calculation means comprise means for
10 estimating the power P_{1n} of the input signal X_{2n} and the power P_{3n} of the signal Y_{3n} and means for calculating a first coupling variable $COR2$ characteristic of the acoustic coupling between the input signal X_{2n} and the signal Y_{3n} from the echo generator system, the adaptation
15 step μ_n of the identification filter being calculated as a function of the estimated powers P_{1n} , P_{3n} and as a function of the first coupling variable $COR2$.

Evaluating the above coupling variable $COR2$ means that the adaptation step of the filter may be "driven" as
20 a function of the real acoustic coupling between the input signal and the output signal of the echo generator system. This improves the responsiveness of the echo canceller as a function of changes in the acoustic environment of the device, and therefore improves the
25 result of echo processing.

In a preferred embodiment, the adaptation step μ_n is obtained from the equation:

$$\mu_n = \frac{P_{1n}}{\alpha \cdot P_{1n} + COR2 \cdot P_{3n}}$$

in which α is a positive constant and P_{1n} and P_{3n}
30 are respectively an estimate of the power of the input signal X_{2n} and an estimate of the power of the signal Y_{3n} from the echo generator system, at the time concerned.

In one embodiment, the adaptation step calculation

means further comprise means for calculating a second coupling variable COR characteristic of the acoustic coupling between the input signal X_{2n} from the echo generator system and the output signal Y_{1n} , the second
 5 coupling variable COR being obtained by calculating the correlation between the input signal X_{2n} and the output signal Y_{1n} , and the adaptation step μ_n of the identification filter being calculated as a function of the second coupling variable COR.

10 By additionally taking account of the second coupling variable COR, it is possible to determine the state of convergence of the identification filter and thus to apply finer control of the adaptation step.

In a third aspect, the invention provides an echo
 15 processing device for a multichannel communications system comprising N receive channels, N being an integer greater than or equal to 2, and M send channels, M being an integer greater than or equal to 1, each of the N receive channels i comprising an output transducer that
 20 produces a sound pressure wave in response to an input signal $X_{2n}(i)$ derived from a direct signal $X_{1n}(i)$, each of the M send channels j comprising an input transducer that converts a sound pressure wave into an output signal $Y_{1n}(j)$, and said echo processing device being adapted to
 25 attenuate, in each output signal $Y_{1n}(j)$, echo components stemming from some or all of the N input signals $X_{2n}(i)$ and resulting from the acoustic coupling between the input transducer of the send channel concerned and some or all of the M output transducers.

30 According to the invention the device is noteworthy in that it comprises:

- means for calculating receive gains $Gr_n(i)$ and send gains $Ge_n(j)$;
- means for applying a receive gain $Gr_n(i)$ to each
 35 direct signal $X_{1n}(i)$ and producing the corresponding

input signal $X_{2n}(i)$:

- means for applying a send gain $Ge_n(j)$ to each output signal $Y_{1n}(j)$ and producing the corresponding return signal $Y_{2n}(j)$; and

5 - means for calculating, for each send channel j , N coupling variables $COR(j,i)$, for i varying from 1 to N , each of which is characteristic of the acoustic coupling between the output signal $Y_{1n}(j)$ of the send channel and one of the N input signals $X_{2n}(i)$;

10 said gain calculation means being adapted to calculate each receive gain $Gr_n(i)$ and each send gain $Ge_n(j)$ on the basis of the N coupling variables $COR(j,i)$ calculated for the associated send channel j .

15 The advantages of this mode of calculating gains in respect of a given pair of send and receive channels (i, j) are of the same kind as are obtained with a variable gain single-channel device of the invention, as briefly set out hereinabove.

20 In a preferred embodiment of the invention, the echo processing device comprises means for estimating the instantaneous power P_{1n_i} of each input signal $X_{2n}(i)$ and the instantaneous power P_{2n_j} of each output signal $Y_{1n}(j)$, said send gain calculation means being adapted to calculate each send gain $Ge_n(j)$ on the basis of N variables $G(j,i)$, for i varying from 1 to N , each of which is determined as a function of the estimated power of an input signal $X_{2n}(i)$ and the estimated power of the output signal $Y_{1n}(j)$ of the send channel concerned and as a function of the corresponding coupling variable

25 $COR(j,i)$, and each of the variables $G(j,i)$ being obtained

30 from the following equation:

$$G(j,i) = \frac{P_{2n_j}}{P_{2n_j} + COR(j,i) \cdot P_{1n_i}}$$

in which P_{1n_i} and P_{2n_j} are respectively an estimate

of the power of the input signal $X_{2n}(i)$ concerned and of the power of the output signal $Y_{1n}(j)$ concerned at the time concerned.

In a fourth aspect, the invention provides an echo
 5 canceller for a multichannel communications system comprising N receive channels, N being an integer greater than or equal to 2, and M send channels, M being an integer greater than or equal to 1, each of the N receive channels i comprising an output transducer that produces
 10 a sound pressure wave in response to an input signal $X_{2n}(i)$, and each of the M send channels j comprising an input transducer that converts a sound pressure wave into an output signal $Y_{1n}(j)$, the device comprising:

- for each send channel j , N identification filters
 15 F_{ij} with variable coefficients for estimating the acoustic coupling between each of the N output transducers and the input transducer of the send channel j , and

- for each filter F_{ij} , means for adapting the
 20 coefficients of the filter as a function of an adaptation step $\mu_n(i,j)$ and means for calculating the adaptation step $\mu_n(i,j)$.

According to the invention, this device is noteworthy in that it comprises:

- means for estimating the instantaneous power P_{1n_i}
 25 of each input signal $X_{2n}(i)$ and the instantaneous power P_{2n_j} of each output signal $Y_{1n}(j)$, and

- means for calculating, for each send channel j , N
 coupling variables $COR(j,i)$, for i varying from 1 to N ,
 30 each of which being characteristic of the acoustic coupling between the output signal $Y_{1n}(j)$ of the same channel and one of the N input signals $X_{2n}(i)$,

- the means for calculating the adaptation step
 $\mu_n(i,j)$ for a filter F_{ij} associated with a receive channel
 35 i and a send channel j , being adapted to calculate the

adaptation step $\mu_n(i,j)$ as a function of the powers $P1n_i$, for i varying from 1 to N, estimated for the N receive channels, as a function of the power $P2n_j$ estimated for the send channel j , and as a function of the N coupling variables $COR(j,i)$, for i varying from 1 to N, associated with the send channel j .

In a preferred embodiment, an adaptation step $\mu_n(i,j)$ for a filter Fij associated with a receive channel i and a send channel j is obtained from the following equation, in which b_i is a positive constant:

$$\mu_n(i,j) = \frac{P1n_i}{b_i \cdot P1n_i + COR(j,i) \cdot P2n_j + \sum_{k \neq i} COR(j,k) \cdot P1n_k}$$

Further features and advantages of the invention will become apparent in the course of the following description of preferred embodiments of the invention, which is given with reference to the appended drawings, in which:

- Figure 1 is a block diagram of a variable gain single-channel echo processing device according to a first embodiment of the invention;
- Figure 2 is a block diagram of a single-channel echo processing device combining a variable gain system and an echo canceller, according to a second embodiment of the invention;
- Figure 3 is a block diagram of a single-channel echo canceller according to a third embodiment of the invention;
- Figure 4 is a block diagram of a single-channel echo canceller according to a fourth embodiment of the invention;
- Figure 5 is a block diagram of a single-channel echo processing device of the invention combining the features of the first and fourth embodiments of the invention;

- Figure 6 is a block diagram of a variable-gain multichannel echo processing device according to a fifth embodiment of the invention; and

- Figure 7 is a block diagram of a multichannel echo
5 canceller according to a sixth embodiment of the invention.

Figure 1 shows a variable-gain single-channel echo processing device according to a first embodiment of the invention. This device is integrated into a hands-free
10 telephone, for example.

As shown in Figure 1, the device receives and sends digital signals X_{1n} , Y_{2n} respectively called the direct signal and the return signal.

The echo processing device comprises a module 36 for
15 calculating the receive gain (Gr_n) and the send gain (Ge_n). The receive gain Gr_n is applied to the direct signal X_{1n} by a multiplier 10 to obtain an input signal X_{2n} that is emitted into an echo generator system 26.

Similarly, the send gain Ge_n is applied to an output
20 signal Y_{1n} from the echo generator system by a multiplier 12 to produce the return signal Y_{2n} .

The input signal X_{2n} is delivered to a loudspeaker
22 via a digital-to-analog converter (DAC) 14 and an amplifier 18. The amplifier 18 is typically a variable-
25 gain amplifier so that a user of the device may adjust the volume of the sound reproduced by the loudspeaker 22 to suit his convenience.

In a similar manner, the output signal Y_{1n} is
obtained from a microphone 24 via an amplifier 20 and an
30 analog-to-digital converter (ADC) 16.

In the embodiment shown, the device comprises a single loudspeaker 22 and a single microphone 24 forming part of the echo generator system 26. However, the device of the invention shown in Figure 1 may equally
35 well be applied to a system in which the input signal X_{2n}

is emitted into the echo generator system by a plurality of loudspeakers 22 reproducing the same sound signal and the output signal Y1n is obtained from the echo generator system by means of a plurality of microphones 24.

5 According to the invention, the echo processing device comprises a module 30 for calculating a coupling variable COR characteristic of the acoustic coupling between the direct signal X1n or the input signal X2n and the output signal Y1n.

10 To this end, the calculation module 30 comprises a calculation unit 34. The coupling variable COR is calculated by the unit 34 and then used by the gain calculation module 36 to calculate the receive gain Gr_n and the send gain Ge_n.

15 In the embodiment shown in Figure 1, the module 30 for calculating the coupling variable COR comprises a unit 28 for estimating the instantaneous power P1n of the input signal X2n and/or the direct signal X1n and an unit for estimating the instantaneous power P2n of the output
20 signal Y1n.

In this embodiment, the gain calculation module 36 is designed to calculate the receive gain Gr_n and the send gain Ge_n on the basis of a variable G calculated by the calculation unit 34 as a function firstly of the
25 estimated power P1n of the direct signal and/or the input signal and the estimated power P2n of the output signal, and secondly as a function of the coupling variable COR.

In a preferred embodiment of the invention, the variable G is determined by the calculation unit 34 from
30 the following equation:

$$G = \frac{P2n}{P2n + COR \cdot P1n} \quad (1)$$

where P1n and P2n are respectively an estimate of the power of the direct signal X1n or the input signal X2n and an estimate of the power of the output signal

Y_{1n}, at the time concerned.

Accordingly, strong coupling (i.e. a high level of correlation) between the direct signal X_{1n} or the input signal X_{2n} and the output signal Y_{1n} yields a low value
 5 of the variable G to cancel echo, whereas weak coupling has the opposite effect on the variable G.

In a preferred embodiment of the invention, the gain calculation means 36 determine the receive gain Gr_n and the send gain Ge_n recursively from the following
 10 equations:

$$\begin{aligned} Ge_n &= \gamma \cdot Ge_{n-1} + (1 - \gamma) \cdot G \\ Gr_n &= 1 - \delta \cdot Ge_n \end{aligned} \quad (2)$$

where Ge_{n-1} is the send gain at the preceding calculation time and γ and δ are positive constants less than 1.

15 The above gain calculation equation (2), which is cited by way of example only, is derived from a calculation disclosed in French patent No. 2 748 184, modified in accordance with the invention to take into account the variable G defined above (equation (1)).

20 In one particular embodiment, good results have been obtained for a calculation at a frequency of 8 kiloHertz (kHz) with γ equal to 0.95.

In the above calculation, the send and receive gains are directly linked to the variable G, which enables
 25 adaptive echo processing as a function of the real characteristics of the echo generator system. Moreover, the range of variation of the send gain Ge_n is a decreasing function of the variable G, enabling automatic enhancement, by increasing the gain, of the sound quality
 30 as perceived by the remote party if the echo component of the signal picked up by the microphone decreases.

Incidentally, it should be noted that the above advantages are obtained without using voice activity

detectors and double voice detectors, which in prior art echo processing devices are complex and sometimes insufficiently reliable.

5 Calculation of the coupling variable COR

According to the invention, the coupling variable COR which characterizes the acoustic coupling between the direct signal X1n or the input signal X2n and the output signal Y1n is obtained by calculating the correlation
10 between the direct signal X1n or the input signal X2 and the output signal Y1n.

An envelope correlation calculation may be used, for example. Thus in one particular embodiment the coupling variable COR is defined as a function of the
15 maximum value Maxcor of the values corr(j) of the correlation between the direct signal X1n or the input signal X2n and the output signal Y1n, said correlation values corr(j) being calculated over a time window considered, and each being obtained from the equation:

$$20 \quad \text{corr}(j) = \frac{\sum_{i=0}^{LM-1} P1(i) \cdot P2(i+j)}{\sum_{i=0}^{LM-1} P1^2(i)} \quad (3)$$

in which \underline{i} is a sampling time in the calculation time window of duration LM, \underline{j} is a shift value between the input signal X2n and the output signal Y1n, and P1(t) and P2(t) are respectively an estimate of the power of
25 the direct signal X1n or the input signal X2n and an estimate of the power of the output signal Y1n, at a time \underline{t} .

In practice, the envelope correlation calculation is effected over time windows of 1 second duration for each
30 signal (input and output) and with a maximum time shift of 300 milliseconds between the signals. The calculation

is effected at a reduced sampling frequency of 125 Hertz.

In this embodiment, very good results are obtained with the variable COR defined by the following equation, in which Exp designates the exponential function and k is a positive constant:

$$COR = \text{Exp}(k \cdot \text{Maxcor}) \quad (4)$$

In practice, very good results are obtained with k equal to 3. Limiting the term $\text{Exp}(3 \cdot \text{Maxcor})$ to 25, corresponding to a maximum correlation of 1.07, is recommended.

A single-channel echo processing device according to a second embodiment of the invention is described next with reference to **Figure 2**. This device combines a variable gain system like that described hereinabove with reference to Figure 1 and an echo canceller.

The echo processing device represented in Figure 2 comprises, like that represented in Figure 1, a module 36 for calculating the receive gain (Gr_n) and the send gain (Ge_n) and a module 30 for determining the variable COR to evaluate the acoustic coupling between the direct signal X_{1n} or the input signal X_{2n} and the output signal Y_{1n} . The features and operation of the Figure 2 modules 30 and 36 are identical to those of the Figure 1 modules.

According to the invention, the device may further include an echo canceller 40 receiving at its input the input signal X_{2n} emitted into the echo generator system 26 and a signal Y_{3n} from the echo generator system 26. The echo canceller 40 conventionally comprises a finite impulse response identification filter 42 whose response is representative of the response of the echo generator system 26.

In operation, the identification filter 42 produces a filtering signal S_n and subtracts the filtering signal S_n from the signal Y_{3n} by means of a subtractor 44. It

then produces the output signal Y_{1n} that is received as input by the multiplier 12, in order to apply to it a send gain Ge_n calculated by the module 36.

In this embodiment, the system is initialized with
5 the echo canceller 40 inactive (the identification filter 42 has not yet converged) to guarantee stability with no Larsen effect. Then, when the filter has converged, the coupling variable COR is evaluated non-intrusively by the module 30. In this embodiment the correlation referred
10 to is that between the direct signal X_{1n} or the input signal X_{2n} and the signal Y_{1n} that constitutes the "residual" signal from the echo canceller 40. The acoustic coupling is then evaluated cyclically to adapt the send and receive gains automatically as a function of
15 acoustic coupling variations.

In this embodiment, the effects of a conventional echo canceller 40 and those of a variable gain echo processing device of the invention (Fig. 1) are combined to optimize echo processing.

20 In practice, in this embodiment, very good results are obtained with the variable COR defined as follows, as a function of Maxcor (see above):

$$COR = 0.75 \cdot \text{Exp}(\text{Maxcor}) \quad (5)$$

A single-channel echo canceller according to a third
25 embodiment of the invention is described next with reference to **Figure 3**. In this embodiment, the principle of estimating the acoustic coupling between the input and output signals of an echo generator system, including calculation of the coupling variable COR as described
30 hereinabove, is applied to calculating the adaptation step of the filter of an echo canceller.

As shown in Figure 3, an echo canceller of the invention conventionally comprises a finite impulse response identification filter 42 whose response is

representative of the response of the echo generator system 26. The echo generator system comprises the combination of the loudspeaker 22, the microphone 24 and their physical environment (walls, background noise, etc.).

The filter 42 receives at its input an input signal X_{2n} that is emitted into the echo generator system 26 via a DAC 14 and an amplifier 18, and generates a filtering signal S_n .

The echo canceller comprises a subtractor 44 that receives a signal Y_{3n} from the echo generator system at its input via an amplifier 20 and an ADC 16. At least one component of the signal Y_{3n} is therefore a response of the echo generator system to the input signal X_{2n} .

Furthermore, the subtractor 44 receives the filtering signal S_n at its input and therefore subtracts the filtering signal S_n from the signal Y_{3n} to produce an output signal Y_{1n} .

The echo canceller comprises a module 46 for updating the coefficients of the identification filter as a function of an adaptation step μ_n . It finally comprises a calculation module 50 for calculating the adaptation step μ_n .

The module 50 for calculating the adaptation step of the filter comprises units 28, 48 for estimating the power P_{1n} of the input signal X_{2n} and the power P_{3n} of the signal Y_{3n} .

The module 50 further comprises a unit 52 for calculating a coupling variable $COR2$ characteristic of the acoustic coupling between the input signal X_{2n} and the signal Y_{3n} coming from the echo generator system 26.

The module 50 finally comprises a unit 54 for calculating the adaptation step. According to the present invention, the adaptation step μ_n of the identification filter is calculated as a function of the

estimated powers $P1n$, $P3n$ and the coupling variable $COR2$.

In a preferred embodiment of the invention, the adaptation step μ_n is obtained from the following equation:

$$\mu_n = \frac{P1n}{\alpha \cdot P1n + COR2 \cdot P3n} \quad (6)$$

in which α is a positive constant and $P1n$ and $P3n$ are respectively an estimate of the power of the input signal $X2n$ and an estimate of the power of the signal $Y3n$ from the echo generator system, at the time concerned.

Evaluating the above coupling variable $COR2$ therefore enables the adaptation step of the filter to be "driven" as a function of the real acoustic coupling between the input signal and the output signal of the echo generator system. This improves the responsiveness of the echo canceller as a function of changes in the acoustic environment of the device - for example after a variation in the sound reproduction volume by the user of the device or use of the device in a noisy environment (street, car, etc.) - and therefore improves the result of echo processing.

According to the same principle as applies to the variable COR defined above in relation to Figure 1, the coupling variable $COR2$ is obtained by calculating the correlation between the input signal $X2n$ and the signal $Y3n$. In practice this is also an envelope correlation calculation. In a preferred embodiment, the coupling variable $COR2$ is defined as being a function of the maximum value $Maxcor2$ of the correlation values $corr2(j)$ calculated over a time window. Each of the correlation values $corr2(j)$ is calculated from the following equation:

$$corr2(j) = \frac{\sum_{i=0}^{LM-1} P1(i) \cdot P3(i+j)}{\sum_{i=0}^{LM-1} P1^2(i)} \quad (7)$$

in which:

i is a sampling time in the calculation time window of duration LM and j is a shift value between the input signal X2n and the signal Y3n; and

P1(t) and P3(t) are respectively an estimate of the power of the input signal X2n and an estimate of the power of the signal Y3n, at the time t concerned.

In this embodiment, very good results have been obtained with the variable COR2 defined by the following equation, in which k is a positive constant:

$$COR2 = \frac{k}{Maxcor2} \quad (8)$$

In a fourth embodiment of the invention, the single-channel echo canceller described hereinabove has added to it a module for calculating a second coupling variable COR, so named by analogy with that from Figure 1, that is characteristic of the acoustic coupling between the input signal X2n of the echo generator system and the output signal Y1n coming from the subtractor 44 of the echo canceller.

Figure 4 shows an echo canceller according to this fourth embodiment. As shown in Figure 4, the echo canceller comprises a module 50 for calculating the adaptation step μ_n similar to that described with reference to Figure 3. The device further comprises a unit 30a for calculating a second coupling variable COR.

The variable COR is characteristic of the acoustic coupling between the input signal X2n of the echo generator system 26 and the output signal Y1n. The

second coupling variable COR is obtained by calculating the correlation between the input signal X2n and the output signal Y1n.

The calculation unit 30a is similar to the unit 30 described above with reference to Figure 1.

In the embodiment shown in Figure 4, the second variable COR is obtained by the same basic process as the variable COR defined above with reference to Figure 1, i.e. by means of an envelope correlation calculation applied to the input signal X2n and the output signal Y1n. In particular, the variable COR is defined as being a function of the maximum value Maxcor of the values of the correlation corr(j) between the input signal X2n and the output signal Y1n.

The second coupling variable COR calculated by the unit 30a is supplied to the unit 54 for calculating the adaptation step μ_n of the filter (see Fig. 3), with the result that this step is also calculated as a function of the second coupling variable COR.

In practice, the adaptation step μ_n is calculated from the following equation:

$$\mu_n = \frac{COR}{COR2} \cdot \frac{P1n}{\alpha \cdot P1n + COR2 \cdot P3n} \quad (9)$$

in which α is a positive constant and P1n and P3n are respectively an estimate of the power of the input signal X2n and an estimate of the power of the signal Y3n from the echo generator system, at the time concerned.

In the embodiment in which the variable COR is a predetermined function f of the variable Maxcor and the variable COR2 is a predetermined function g of the variable Maxcor2 (see above), the above equation (9) may be expressed in the following form:

$$\mu_n = \frac{f(Maxcor)}{g(Maxcor2)} \cdot \frac{P1n}{\alpha \cdot P1n + COR2 \cdot P3n} \quad (9a)$$

By additionally taking into account the second coupling variable COR, it is possible to determine the state of convergence of the identification filter and thus to achieve finer control of the adaptation step.

5 Another embodiment of the invention combines the echo processing device described above with reference to Figure 1 and the device described above with reference to Figure 4. **Figure 5** shows a device of this kind.

10 In Figure 5, the items referenced 10, 12, 36, 30 are identical to those represented in Figure 1 and constitute a variable gain single-channel echo processing device of the invention. Furthermore, the items 50, 46, 40 are identical to those of the echo canceller shown in Figure 4. When the units 30 and 50 are adapted so that the unit
15 30 is able to supply the variable COR to the unit 50 and the unit 50 is able to calculate the adaptation step of the filter 42 as a function of the variables COR, COR2, as explained above, then a combination of the systems described with reference to Figures 1 and 4 is obtained
20 that combines the advantages of each of those two systems.

The present invention also applies to echo processing devices intended for a multichannel communications system.

25 A variable gain multichannel echo processing device constituting a fifth embodiment of the invention is described next with reference to **Figure 6**.

As shown in Figure 6, a variable gain multichannel echo processing device of the invention is intended to be
30 used in a multichannel communications system comprising N receive channels, where N is an integer greater than or equal to 2, and M send channels, where M is an integer greater than or equal to 1.

Each of the N receive channels i comprises an output

transducer LS_i , typically a loudspeaker, which produces a sound pressure wave in response to an input signal $X_{2n}(i)$ derived from a direct signal $X_{1n}(i)$.

Each of the M send channels j comprises an input
 5 transducer MC_j , typically a microphone, which converts a sound pressure wave into an output signal $Y_{1n}(j)$.

An echo processing device of the above kind is intended to attenuate in each output signal $Y_{1n}(j)$ echo components stemming from some or all of the N input
 10 signals $X_{2n}(i)$ and resulting from acoustic coupling between the microphone of the send channel concerned and some or all of the N loudspeakers.

As shown in Figure 6, a variable gain multichannel echo processing device of the invention comprises a
 15 module 64 for calculating receive gains $Gr_n(i)$ and send gains $Ge_n(j)$.

It further comprises N multipliers 68 adapted to apply a receive gain $Gr_n(i)$ to each direct signal $X_{1n}(i)$ and produce the corresponding input signal $X_{2n}(i)$.

20 Similarly, the device comprises multipliers 66 adapted to apply a send gain $Ge_n(j)$ to each output signal $Y_{1n}(j)$ and produce a corresponding return signal $Y_{2n}(j)$.

It further comprises a module 62 for calculating N coupling variables $COR(j,i)$, for i varying from 1 to N ,
 25 for each send channel j , each of the N variables being characteristic of the acoustic coupling between the output signal $Y_{1n}(j)$ of the send channel j concerned and one of the N input signals $X_{2n}(i)$.

According to the invention, the gain calculation
 30 module 64 calculates each receive gain $Gr_n(i)$ and each send gain $Ge_n(j)$ on the basis of the N coupling variables $COR(j,i)$ calculated for the associated send channel j .

The advantages relating to this gain calculation method with respect to a given pair (i,j) of receive and
 35 send channels are of the same nature as those obtained

with the variable gain single-channel device of the invention described above with reference to Figure 1.

Furthermore, a preferred embodiment of the multichannel echo processing device shown in Figure 6
 5 comprises a power calculation module (not shown) adapted to estimate the instantaneous power $P1n_i$ of each input signal $X2n(i)$ and the instantaneous power $P2n_j$ of each output signal $Y1n(j)$.

In this embodiment, the correlation variable COR
 10 calculation module 62 also calculates N variables $G(j,i)$ for i varying from 1 to N , each of which is determined as a function of the estimated power $P1n$ of an input signal $X2n(i)$ and the estimated power $P2n_j$ of the output signal $Y1n(j)$ of the send channel concerned. According to the
 15 invention, each of the variables $G(j,i)$ is obtained from the following equation:

$$G(j,i) = \frac{P2n_j}{P2n_j + COR(j,i) \cdot P1n_i} \quad (10)$$

in which $P1n_i$ and $P2n_j$ are respectively an estimate of the power of the input signal $X2n(i)$ concerned and an
 20 estimate of the power of the output signal $Y1n(j)$ concerned, at the time concerned.

The gain calculation module 64 then calculates each send gain $Ge_n(j)$ on the basis of the N variables $G(j,i)$ as a function of the corresponding coupling variable
 25 $COR(j,i)$.

In a preferred embodiment, each send gain $Ge_n(j)$ is determined from the minimum value of the N variables $G(j,i)$, for i varying from 1 to N , calculated for the associated send channel j .

30 In practice, each send gain $Ge_n(j)$ is determined from the following equation:

$$Ge_n(j) = \gamma \cdot Ge_{n-1}(j) + (1 - \gamma) \cdot \min_i(G(j,i)) \quad (11)$$

in which $Ge_{n-1}(j)$ is the send gain of the send

channel j at the time of the preceding calculation, γ is a positive constant less than 1, and $\min_i(G(j,i))$ is the minimum value of the N variables $G(j,i)$ for i varying from 1 to N .

5 Taking the minimum value $\min_i(G(j,i))$, the lowest gain (i.e. the highest attenuation) is applied to the channel j concerned, this gain therefore taking into account the greatest coupling value on all possible echo paths of the system.

10 Preferably (although this is not mandatory), in combination with the method of calculating the send gain explained hereinabove, all the receive gains $Gr_n(i)$ have the same value, determined from the following equation:

$$Gr_n(i) = 1 - \delta \cdot \max_j(Ge_n(j)) \quad (12)$$

15 in which δ is a positive constant less than 1 and $\max_j(Ge_n(j))$ is the maximum value of the M send gains $Ge_n(j)$, for j varying from 1 to M .

However, in a different embodiment of the device, shown in Figure 6, each receive gain $Gr_n(i)$ is made equal
20 to 1. This solution has the advantage of simplifying the calculation of the gains, combined with very good echo processing results.

Calculation of each coupling variable $COR(j,i)$

According to the invention, each coupling variable
25 $COR(j,i)$ is obtained from a calculation of the correlation between the corresponding output signal $Y1n(j)$ and input signal $X2n(i)$. In a preferred embodiment, the calculation is an envelope correlation calculation.

30 In practice, each coupling variable $COR(j,i)$ is obtained from the maximum value $Maxcor$ of the values $corr_{ji}(d)$ of the correlation between the corresponding output signal $Y1n(j)$ and input signal $X2n(i)$, these correlation values $corr_{ji}(d)$ being calculated over a

predefined time window. Each of the correlation values is obtained from the following equation:

$$corr_{ji}(d) = \frac{\sum_{c=0}^{LM-1} P1n_i(c) \cdot P2n_j(c+d)}{\sum_{c=0}^{LM-1} P1n_i^2(c)} \quad (13)$$

in which \underline{c} is a sampling time in the calculation time window of duration LM, \underline{d} is a shift value between the input signal $X2n(i)$ and the output signal $Y1n(j)$, and $P1n_i(t)$ and $P2n_j(t)$ are respectively an estimate of the power of the input signal $X2n(i)$ and an estimate of the power of the output signal $Y1n(j)$ at a time \underline{t} .

A multichannel echo canceller constituting a sixth embodiment of the invention is described next with reference to **Figure 7**. This embodiment may be considered as a generalization to the multichannel situation of the single-channel echo cancellers described above with reference to Figures 3 and 4.

As shown in Figure 7, a multichannel echo canceller of the invention comprises N receive channels, where N is an integer greater than or equal to 2, and M send channels, where M is an integer greater than or equal to 1.

Each of the N receive channels \underline{i} comprises an output transducer (loudspeaker) LS_i that produces a sound pressure wave in response to an input signal $X2n(i)$. Each of the M send channels \underline{j} comprises an input transducer (microphone) MC_j that converts a sound pressure wave into an output signal $Y1n(j)$.

Furthermore, the echo canceller comprises, for each send channel \underline{j} , N identification filters F_{ij} with variable coefficients for estimating the acoustic coupling between each of the N loudspeakers LS_i and the microphone MC_j of the send channel \underline{j} . It further

comprises, for each filter F_{ij} , means (not shown) for adapting the coefficients of the filter as a function of an adaptation step $\mu_n(i,j)$ and means (not shown) for calculating the adaptation step $\mu_n(i,j)$.

5 Each filter F_{ij} associated with a receive channel i and a send channel j generates a filtering signal that is subtracted from the output signal $Y_{1n}(j)$ to produce a filtered signal $Y_{2n}(j)$.

10 According to the invention, the device further comprises means (not shown) for estimating the instantaneous power P_{1n_i} of each input signal $X_{2n}(i)$ and the instantaneous power P_{2n_j} of each output signal $Y_{1n}(j)$.

15 It also comprises means (not shown) for calculating, for each send channel j , N coupling variables $COR(j,i)$, for i varying from 1 to N , each of which being characteristic of the acoustic coupling between the output signal $Y_{1n}(j)$ of the send channel concerned and one of the N input signals $X_{2n}(i)$.

20 The means for calculating the adaptation step $\mu_n(i,j)$ for a filter F_{ij} associated with a given receive channel i and a given send channel j calculate the adaptation step $\mu_n(i,j)$ as a function of:

- the estimated powers P_{1n_i} (for i varying from 1 to N) calculated for the N receive channels i ,
- 25 - the estimated power P_{2n_j} calculated for the send channel j , and
- the N coupling variables $COR(j,i)$, for i varying from 1 to N , associated with the send channel j concerned.

30 Calculation of each coupling variable $COR(j,i)$

35 In this embodiment, each coupling variable $COR(j,i)$ is obtained from a correlation calculation between the output signal $Y_{1n}(j)$ and the input signal $X_{2n}(i)$ associated with the pair of receive and send channels (i,j) concerned.

As in the other embodiments of the invention described above, in a preferred embodiment, the correlation calculation is an envelope correlation calculation.

5 In practice, each coupling variable $COR(j,i)$ is obtained from the maximum value $Maxcor(j,i)$ of the values $corr_{ji}(d)$ of the correlation calculated over a respective predefined time window, each of the correlation values $corr_{ji}(d)$ being calculated from the following equation:

$$10 \quad corr_{ji}(d) = \frac{\sum_{c=0}^{LM-1} P1n_i(c) \cdot P2n_j(c+d)}{\sum_{c=0}^{LM-1} P1n_i^2(c)} \quad (14)$$

in which \underline{c} is a sampling time in the calculation time window of duration LM , \underline{d} is a shift value between the input signal $X2n(i)$ and the output signal $Y1n(j)$, and $P1n_i(t)$ and $P2n_j(t)$ are respectively an estimate of the
15 power of the input signal $X2n(i)$ and an estimate of the power of the output signal $Y1n(j)$ at a time \underline{t} .

In practice, each coupling variable $COR(j,i)$ is related to the maximum value $Maxcor(j,i)$ of the correlation values $corr_{ji}(d)$ by the following equation, in
20 which \underline{k} is a positive constant:

$$COR(j,i) = \frac{k}{Maxcor(j,i)} \quad (15)$$

Calculation of the adaptation step $\mu_n(i,j)$ for a filter Fij

25 In this embodiment, an adaptation step $\mu_n(i,j)$ for a filter Fij associated with a receive channel \underline{i} and a send channel \underline{j} is obtained from the following equation, in which b_i is a positive constant:

$$\mu_n(i, j) = \frac{Pln_i}{b_i \cdot Pln_i + COR(j, i) \cdot P2n_j + \sum_{k \neq i} COR(j, k) \cdot Pln_k} \quad (16)$$

Thanks to the presence in the above expression of the term $\sum_{k \neq i} COR(j, k) \cdot Pln_k$ for the step $\mu_n(i, j)$, the receive channels other than the channel i concerned do not
 5 interfere with the convergence of the filter F_{ij} , and this is achieved in conjunction with automatic reduction of the value of the step. Furthermore, the presence of the variables $COR(j, k)$ provides an indication of the real influence on the send channel j concerned of receive
 10 channels other than the channel i concerned.

In a similar manner to the single-channel situation described above with reference to Figure 4, an embodiment of the multichannel echo canceller, shown in Figure 7, may further comprise means for calculating, for each send
 15 channel j, N second coupling variables $COR2(j, i)$ for i varying from 1 to N.

Each of the second coupling variables is characteristic of the acoustic coupling between the filtered signal $Y2n(j)$ of the send channel j concerned
 20 and one of the N input signals $X2n(i)$.

In this embodiment, the adaptation step $\mu_n(i, j)$ of an identification filter F_{ij} associated with a receive channel i and a send channel j is calculated as a function of the first N coupling variables $COR(j, i)$ and
 25 the second N coupling variables $COR2(j, i)$.

In a preferred embodiment, the adaptation step $\mu_n(i, j)$ for a filter F_{ij} associated with a receive channel i and a send channel j is obtained from the following equation, in which b_i is a positive constant:

$$30 \quad \mu_n(i, j) = \frac{COR(j, i)}{COR2(j, i)} \cdot \frac{Pln_i}{b_i \cdot Pln_i + COR(j, i) \cdot P2n_j + \sum_{k \neq i} COR(j, k) \cdot Pln_k} \quad (17)$$

A variable gain multichannel echo processing device of the invention (Fig. 6) may be combined with a multichannel echo canceller of the invention (Fig. 7) to combine their advantages.

5 In this case, this kind of multichannel device (not shown in the drawings) comprises, for each pair comprising a receive channel i and a send channel j , gain application means adapted to apply a receive gain $Gr_n(i)$ to the input signal $X2n(i)$ and a send gain $Ge_n(j)$ to the
10 filtered signal $Y2n(j)$.

 The gains $Gr_n(i)$, $Ge_n(j)$ are then calculated on the basis of the N second coupling variables $COR2(j,i)$ determined for the send channel j , using the same basic principle as the device described above with reference to
15 Figure 6.

 In practice, the various echo processing devices of the present invention described hereinabove may be obtained in the usual way by programming a digital signal processor (DSP). They may also be implemented by means
20 of application-specific integrated circuits (ASIC).

 Of course, the present invention is in no way limited to the embodiments described here, and to the contrary encompasses any variant that will be evident to the person skilled in the art.